Accretion and extensional collapse of the external Western Rif (Northern Morocco)

J. F. Flinch

Department of Geology and Geophysics,
Rice University, Houston,
TX 77251-1892, USA
Present address : Departamento de Geologia,
Lagoven, Caracas 1010-A-889, Venezuela

ABSTRACT

The frontal part of the Gibraltar Arc consists of allochthonous tectono-sedimentary complexes classically interpreted as gravity driven units or "melange". High quality seismic data along the northwestern Moroccan Atlantic margin and the Rharb Basin, as well as field data in the Western Rif provide a new view of this complex region. The overall type of deformation suggests an accretionary prism involving deep-water sediments, that was emplaced on the attenuated passive margins of Iberia and Africa in response to westward motion of the Alborán domain during the Miocene. The timing of deformation and the age of the sediments involved suggest an accretionary progression towards the external portion of the Arc.

Late Miocene and Pliocene extensional collapse of the unestable accretionary prism controls the structure of the region. The geometry of the extensional system present in the frontal accretionary wedge of the Rif Cordillera is very similar to the one of the Gulf of Mexico.

Data presented here suggests that some units classically interpreted as thrust sheets are in fact mixed extensional-compressional "satellite" basins.

1 REGIONAL SETTING

The Western Mediterranean region consists of a collage of several blocks located between the Euro-Asiatic and the African plates. These intermediate blocks or micro-plates (i.e. Iberia, Alborán, Corsica-Sardinia and Apulia) interacted with each other and with Eurasia and Africa, defining the geodynamics of the region (Dercourt et al., 1986; Andrieux et al., 1989; Dewey et al., 1989; Ziegler, 1987; Favre and Stamfli, 1992).

The Gibraltar Arc is the western limit of the Alpine-Mediterranean system. The Betic Cordillera in southern Spain and the Rif Cordillera in northern Morocco constitute the northern and southern part of the Arc (Fig. 1). The geological units of the Betic and Rif Cordilleras can be subdivided, as most of the Alpine orogens, into an External and an Internal domain.

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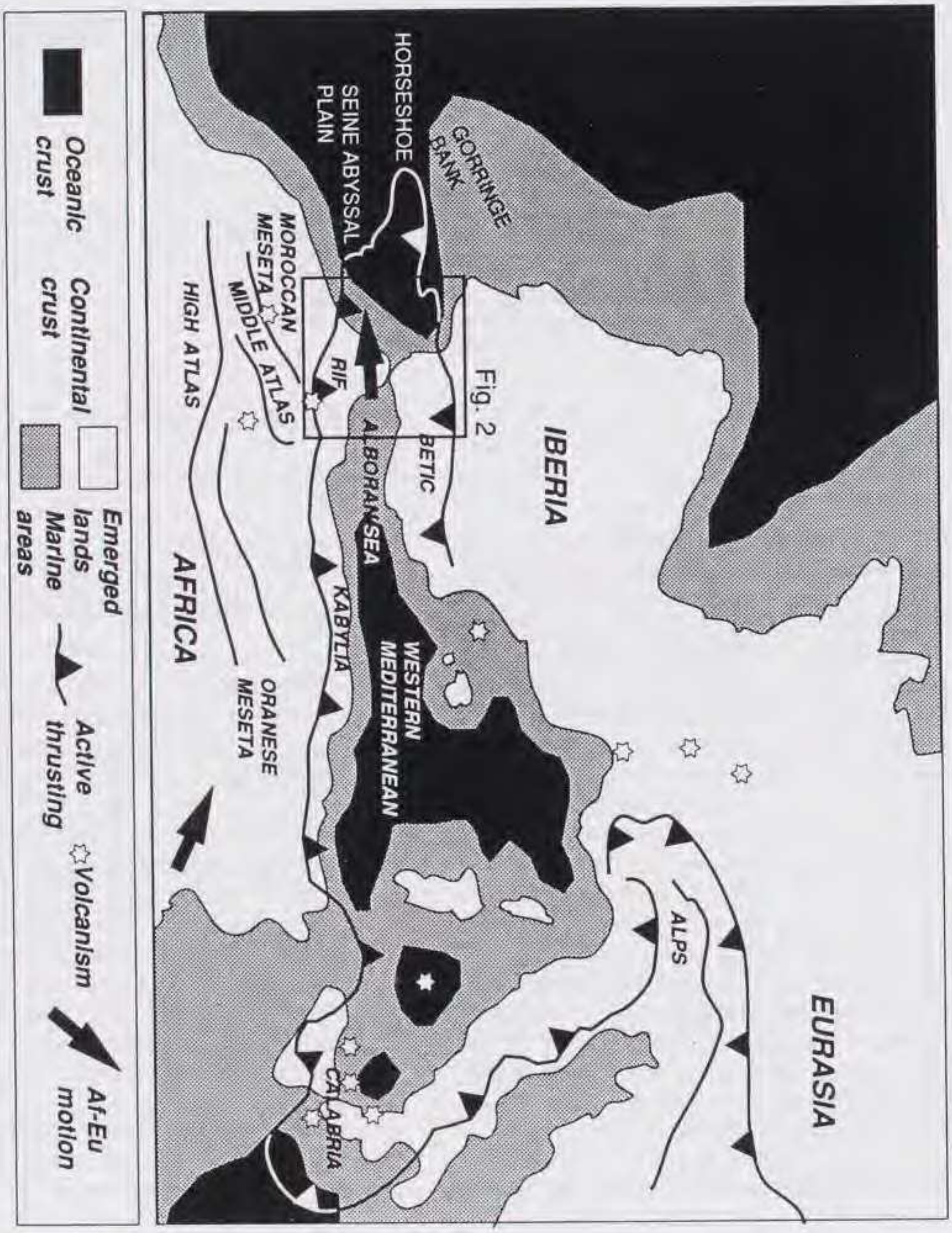

FIG. 1. Location of the study area within the Western Mediterranean Alpine system. Present-day structural sketch, modified after Dercourt et al. (1986) and Dewey et al. (1989).

Classically, the **External domain** of an orogenic belt is represented by non-metamorphic sedimentary successions, characterized by thin-skinned tectonics. The **External domain** of the Betic and Rif Cordilleras is separated into a number of structural units or thrust sheets (García-Hernández et al., 1980; Vera, 1983; Wildi, 1983). Some thrust sheets consist primarily of platform carbonates and other sheets consist mostly of siliciclastic sediments. The different types exhibit widely different styles of decollement tectonics. The **External domain** of the Betic and Rif Cordillera represents, respectively, the south-Iberian and north-African passive margin successions incorporated into the folded belt (Michard, 1976; Vera, 1981; Wildi, 1983; Martín-Algarra, 1987).

The **Internal** or **Alborán domain**, which includes the Internal zones of the Betic and Rif Cordilleras (Fig. 2), differs stratigraphically and structurally from the External zones (Suter, 1965; Fontboté, 1983). The most notable characteristics that distinguish the Internal from the External zones include: Alpine-type Triassic carbonates, Early Alpine (Cretaceous-Paleogene) polyphase compressional deformation and HP/LT metamorphism (Fontboté, 1983; Wildi, 1983; Galindo-Zaldivar et al., 1989; De Jong, 1991). The lowermost unit, the Nevado-Filabrides, is only present in the Betic Cordillera (Fig. 3a). The intermediate Alpujarrides-Sebtides unit contains metamorphic rocks and mantle peridotites (Beni-Bousera and Ronda ultramafics). The upper unit (Ghomarides-Malaguides) overlies both the Sebtides and the Dorsale unit.

Neogene extension associated with the collapse of the Alborán Sea and late inversion and transpressional tectonics severely modified the overall compressional development of the Gibraltar Arc (García-Dueñas et al., 1992; Flinch, 1993). Equivalent structural units of the Betics and the Rif are presently separated by the Alborán Sea. Extensional delamination accounts for dramatical thinning of the Internal domain units, resulting in stratigraphic omission (García-Dueñas and Martínez-Martínez, 1989; García-Dueñas et al., 1992). The structure of the extended Internal domain is similar to core-complexes of the Basin and Range province of the Western United States (Galindo-Zaldívar et al., 1989).

Two generalized regional geological cross-sections were constructed to compare the structure of the Betic and the Rif Cordilleras (Fig. 3). These sections are in part based on reflection seismic data (Blankenship, 1992; Flinch, 1993), well-logs (IGME 1987) and surface geological data (Suter, 1980a, 1980b; Blankenship, 1992; García-Dueñas et al., 1992; Flinch, 1993). They provide a broad approximation of the Gibraltar Arc structure and help to define the main structural problems. At a first look both cross-sections show great similarities. The Rif and the Betic Cordilleras are both characterized by foreland-vergent thin-skinned piggy-back thrusting involving the passive margin succession of the north-African or south-Iberian domains and a main Triassic decollement. Extensional structures affect the Internal domain of both fold and thrust belts, often reactivating previous thrust sheets (negative inversion). The Frontal tectono-sedimentary unit, referred to as Guadalquivir Allochthon in the Betic Cordillera and the Prerifaine Nappe in the Rif, is equivalent to both sides of the Gibraltar Straits.

The main difference between these fold belts is that the Betic is a carbonate dominated margin, while the Rif is a detritic dominated margin. The principal problems of the area concern the role of extension related to the opening of the Alborán Sea, the role of strike-slip faults, the way per which the shortening in the lower part of the passive margin succession is accomodated, the area of origin of the frontal allochthonous tectono-sedimentary complexes and the sequence of thrust emplacement.

2 THE ACCRETIONARY ZONE

The frontal units of the Betic and Rif Cordilleras (i.e. Frontal tectono-sedimentary Complex) consist of highly deformed Triassic, Cretaceous, Paleogene and Neogene strata, which were detached from their original base and thrust over the Mesozoic to Lower Miocene of the foreland. This unit is known as the "Guadalquivir allochthonous units" in the Betic Cordillera which is equiva-

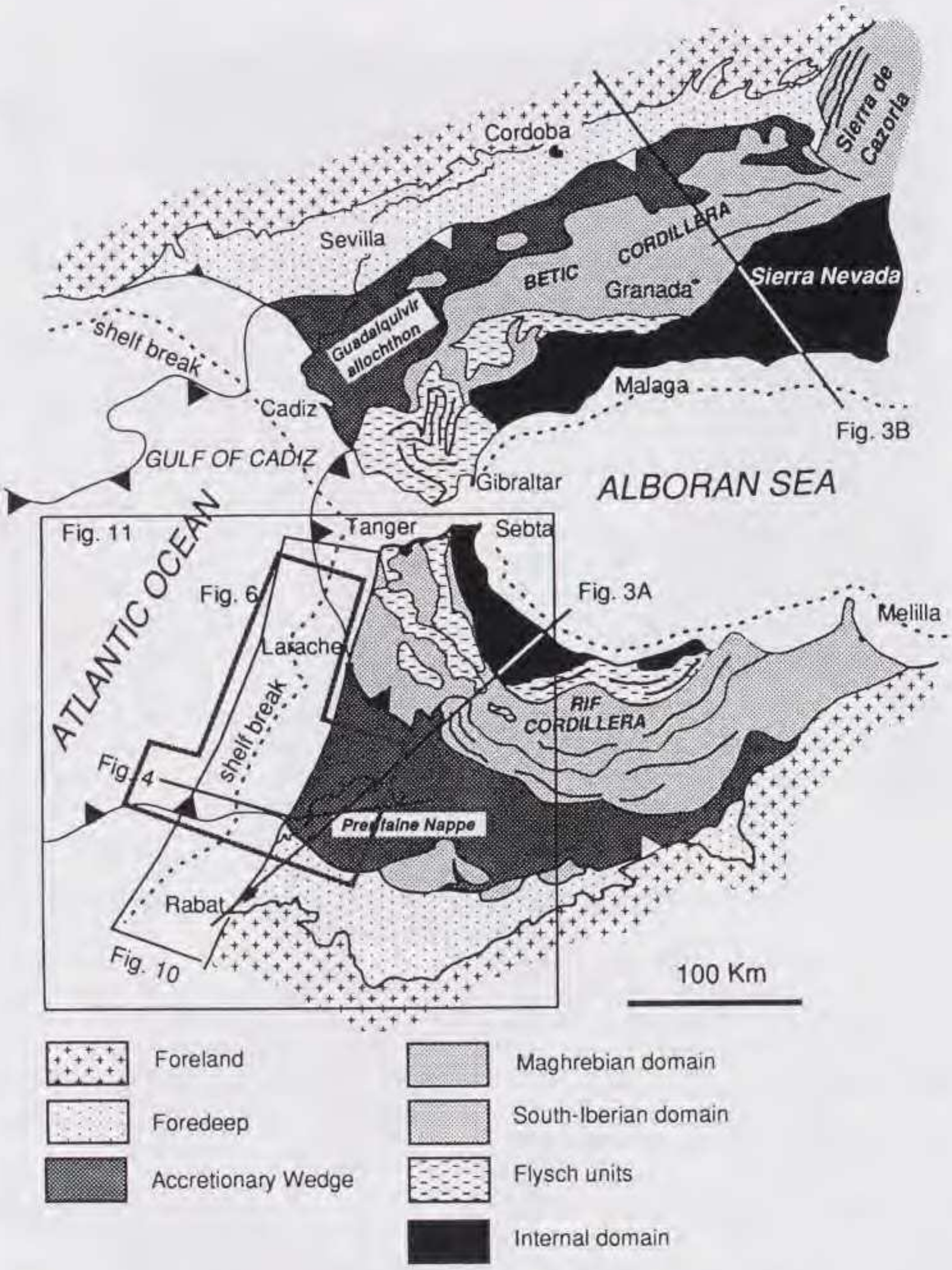

FIG. 2. Tectonic map of the Gibraltar Arc, after Flinch (1993). Location of the study area and following figures.

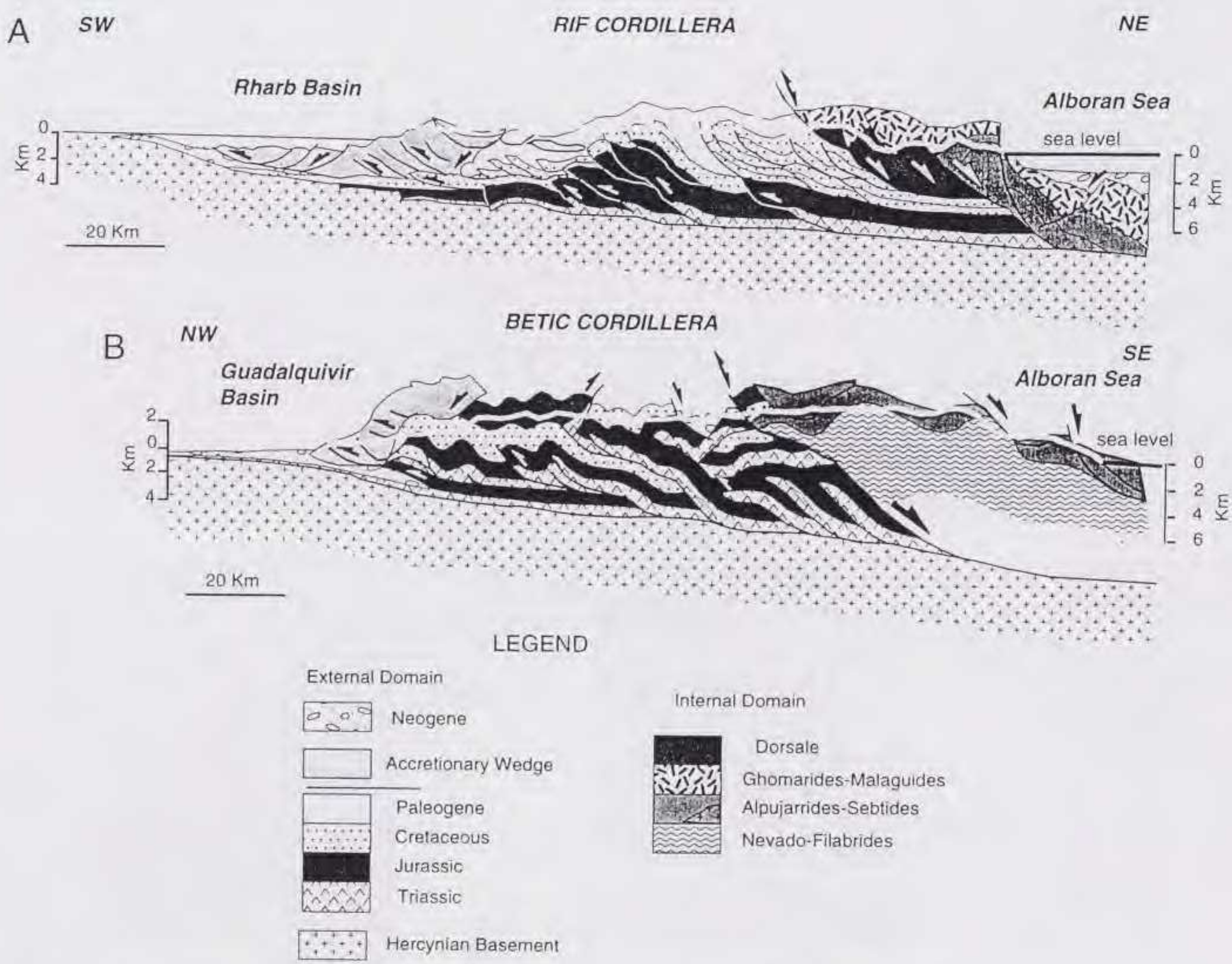

FIG. 3. Cross-sections of the Betic and Rif Cordilleras. Based on subsurface and surface data from Suter (1980a), Blankenship (1992) and García-Dueñas et al. (1992).

lent to the Prerifaine Nappe of the Moroccan Rif. Both the Guadalquivir Allochthon and the Prerifaine Nappe constitute an up to 100 km wide belt (Fig. 2). The frontal allochthonous units of the Betic Cordillera (i.e. the Guadalquivir allochthonous units) extend into the Gulf of Cádiz and farther west to the so-called Horseshoe or "Fer du Cheval", east from Gorringe Bank and the Seine abyssal plain in the Central Atlantic (Fig. 1) (Lajat et al., 1975; Malod and Didon, 1975; Malod and Mougenot, 1979).

Near Gibraltar the inner units of the Arc are bounded by the so called Flysch units, which consists of deep-water shales and turbiditic sandstones.

The Guadalquivir Allochthon incorporates voluminous Triassic shales and evaporites, as well as marls, carbonates and siliciclastics (Perconig, 1960-62). In contrast, the Prerifaine Nappe includes only minor amounts of Triassic evaporites, but mainly younger detritic turbidites or shales (Daguin, 1927; Termier, 1936; Bruderer and Lévy, 1954; Tilloy, 1955a, 1955b, 1955c, 1955d). In the following I will focus on the southern part of the Gibraltar Arc, in the accretionary zone of the Rif Cordillera, classically refered to as the **Prerifaine Zone** (Suter, 1965).

2.1 Stratigraphy

The sedimentary prism of the accretionary wedge can be subdivided into three major tectonostratigraphic units: Supra-Nappe, Nappe and Infra-Nappe. Due to the lack of offshore wells (only a shallow well was drilled offshore Larache, see Fig. 6 for location) stratigraphic information offshore is largely based on correlation with onshore data (Flinch, 1993). Onshore wells were tied to seismic sections and correlated with offshore data. Section of Figure 5 illustrates an example of onshore-offshore correlation.

In the study area few wells have penetrated the sedimentary succession located below the Prerifaine Nappe (Fig. 5). Cretaceous and Lower to Middle Miocene strata unconformably overlie metamorphic and igneous Paleozoic rocks of the Hercynian Basement. Locally a Triassic shaly and evaporitic section was encountered. Seismic data demonstrates that Triassic sediments occupy extensional half-grabens. The Cretaceous and Lower-Middle Miocene section represents the cover of the Morocan Meseta. The lack of Jurassic in this area is explained by some authors as a result of shoulder uplift related to the opening of the Central Atlantic (Favre et al., 1991; Favre and Stampfli, 1992). The sedimentary succession encountered by exploratory wells in the Rharb Basin is similar to the stratigraphic section exposed in the western Moroccan Meseta described by Gigout (1951).

The Prerifaine Nappe consists of Triassic to Miocene sediments that are bounded by stratigraphic and/or tectonic contacts (Bruderer and Lévy, 1954). The stratigraphy for the Prerifaine Nappe is obscured by complex deformation. Resedimentation and the presence of reworked Cretaceous faunas (i.e. ammonites) together with Triassic and Miocene sediments leads to difficult biostratigraphic problems (Feinberg, 1986). Thickness estimates are not easily made. The stratigraphy of the Prerifaine Nappe is based on very few outcrops located in the areas surrounding the Rharb Basin and on exploration wells located within the basin. The following description of the stratigraphy is based on surface data obtained by the SCP (Tilloy, 1955a, 1955b, 1955c, 1955d; Feinberg, 1986) and information from exploration wells that penetrated the Nappe. Table 1 describes the lithology and fossil content of the Prerifaine Nappe. The Neogene planktonic biozonation is derived from Feinberg (1986) and Wernli (1988). Even though there is not a discernable stratigraphic order because of imbrication and reworking, the sediments involved in the Nappe proceed from older to younger.

The Supra-Nappe complex consists of a seaward prograding wedge that ranges in age from Late Miocene to Holocene. However the presence of restricted anoxic environments poor in planktonic faunas, resedimentation and tectonic complications hinder the establishment of a generalized biostratigraphy. The litoral faunas of the peripheral regions of the Rharb Basin are difficult to correlate with the pelagic faunas of the center of the basin.

The Neogene biostratigraphy of the Rharb and Rif areas, was based on Wernli (1988). The Supra-Nappe subsurface stratigraphy of the Rharb Basin based on selected wells is shown in Fig. 5.

AGE	LITHOLOGY	FORAMINIFERA	THICKNESS	BOUNDARIES	COMMENTS
Middle Miocene	Interbedded sandy-marl and sandstone with occasional limestone beds.	*Globorotalia miozea rifensis* *Orbulina suturalis*	200-300 m	Transitional	
Lower Miocene	Interbedded sandstone and marl with occasional marly-limestone levels.	*G. klugeri, G. primordius, G. trilobus* *G. deshincens, G. bisphericus.*	100-300 m	Transitional	
Upper Oligocene	Interbedded marl and turbiditic sandstone with occasional breccia intervals and limestone beds.	*G. angulisuturalis*	150-200 m		Paleontologic problems to define the Oligo-Miocene boundary.
Lower Oligocene		*Lepidocyclina sp. Amphistegina sp* *G. ampliapertura G. evapertura* *G,. gortanii G. sellii G. ampliapertura*		Transitional	
Upper Eocene	Interbedded limestone and sandstone	*G. semmiinvoluta* *G. cocoaensis*	400 m	Transitional	
Middle Eocene	Interbedded marly-siltstone and sandstone with conglomerates and olistostromes	*Hantkenina aragonensis* *Globigerinatheka subconglobata subconglobata* *Globorotalia lehneri*	450-500 m	Transitional	
Lower Eocene	White marl and grey marly-limestone with nodular silex.	*G. caucasica, G. palmerae, G. aragonensis* *G. lensiformis G. marginodentata*	200-300 m		These facies are referred to locally as "marnes blanches a silex"" or" le Numulitique" due to the abundance of Numulites
Upper Paleocene		*G. pseudomenardii, G. velascoensis*			
Lower Paleocene		*G. edita, G. pseudobulloides, G. compressa* *G. elongata, G. triloculinoides, G. daubjergensis* *G. trinitatensis.*		Transitional	
Upper Cretaceous	Magnesium-bearing green marly-shale with planktonic foraminifera	*Trinitella scotti, Plummerita hantkeninoides* *Globotruncana sp.*	?		Triassic evaporites with blocks of sedimentary, volcanic and metamorphic rocks appear to be interbedded with Cretaceous marls
Lower Cretaceous	Albian calci-turbidites consisting of interbedded marl and marly-limestone Ammonite-bearing Neocomian gray marl and white marly limestone	?	?	Tectonic or diapiric	
Triassic	Varicolored and often purple marl with interbedded salt and gypsum. Occasional diabase and pillow-lavas	?	?		Locally blocks of Paleozoic gneiss micaschist or organic rich black schist are intermixed with Triassic

TABLE 1

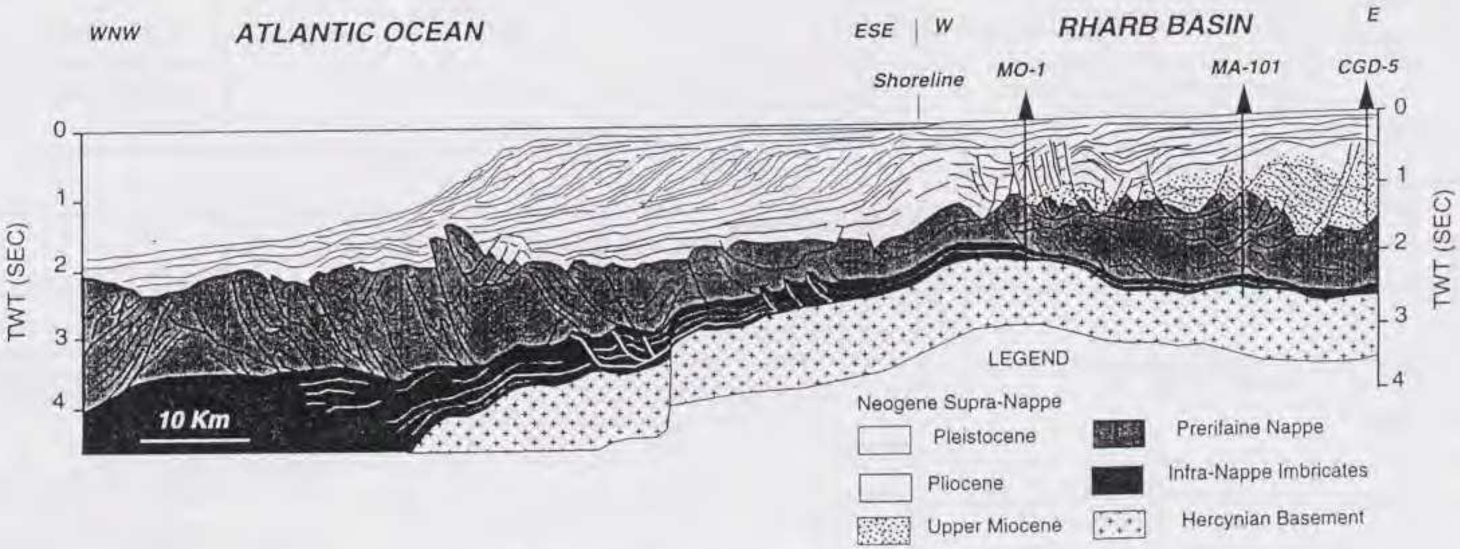

FIG. 4. Cross-section of the Accretionary Wedge in the Western Rif outlining the Offshore-Onshore correlation. Notice that the apparent gentle westward deepening of the wedge is a velocity effect due to the water column.

3 STRUCTURE OF THE EXTERNAL WESTERN RIF

Reflection seismic, well-log and field data were integrated to provide an understandable picture of the external part of the Western Rif. Subsurface data is specially important in this area due to the lack of good surface exposures. A large number of seismic profiles covering the northwestern Atlantic margin of Morocco were used to map the structure of the Prerifaine Nappe in the offshore region. Mapping permits to establish the offshore prolongation of the Rif frontal thrusts, the leading edge of the frontal accretionary wedge and the contact between extensional and compressional provinces (see Fig. 6). A complex set of basins can be outlined within the accretionary zone (Flinch and Bally, 1991).

3.1 Regional Transects

Five NE-SW offshore regional sections, extending from Asilah to Rabat, have been selected to show the structure of the northwestern Moroccan Atlantic margin (Fig. 6 and Enclosure 1). The transects display a variety of structural styles. According to the seismic character and structural significance, a number of structural units are differentiated, from bottom to top:

(1) Acoustic basement: Paleozoic.
(2) Infra-Nappe: Mesozoic and Lower Miocene cover of the Paleozoic basement.
(3) Prerifaine Nappe: Accretionary Wedge.
(4) Supra-Nappe: Upper Miocene and Plio-Pleistocene siliciclastics.

In the following these units will be referred to as: Basement, Infra-Nappe, Nappe and Supra-Nappe. The NE-SW oriented sections (Enclosure 1) traverse the main structural units of the accretionary complex shown on the structural map (Fig. 6). The regional sections will be described proceeding from the southern foreland basin to the northern frontal folded belt. The southern part of the transects shows northward-dipping layered reflectors of the foreland which project under the frontal imbricates of the accretionary complex. These reflectors are occasionally detached from the acoustic basement to form imbricates. The frontal imbricates are characterized by thrust planes which dip steeply to the north. Thrust sheets emanate from a gently northward-dipping basal décollement which separates them from the underlying autochthon. Proceeding northward, the complex is overprinted by northward-dipping normal faults and associated extensional basins with no significant growth. Further north, extensional faults step down and confine thick extensional basins. They constitute the southern part of an extensional system running nearly perpendicular to the plane of the sections. Ridges cored by folded accretionary complex sediments occur in the central region of the extensional system. The southern branch of the extensional system is characterized by northward-dipping normal faults. These faults are connected with conjugate southward-dipping listric normal faults that often constitute the lateral ramps of the extensional system. The central portion of the extensional basin, with its high ridges and deep troughs, is detached from the basal extensional contact. This portion of the margin provides exceptional sections across the extensional system. Proceeding northward, the northern branch of the extensional system cuts thrusts and folds of the underlying accretionary complex. The northern portion of the sections is characterized by north-dipping thrust planes and related ramp anticlines.

According to the data presented here, the study region can be subdivided into several structural domains (Fig. 6): Offshore Tanger-Asilah Compressional Belt, Offshore Larache Extensional Zone, Offshore Rharb Compressional-Extensional Zone, Rharb Basin and Rabat Foreland Basin. To facilitate the presentation of the data, the offshore data will be presented separate from the data of the Rharb Basin, despite their structural affinity.

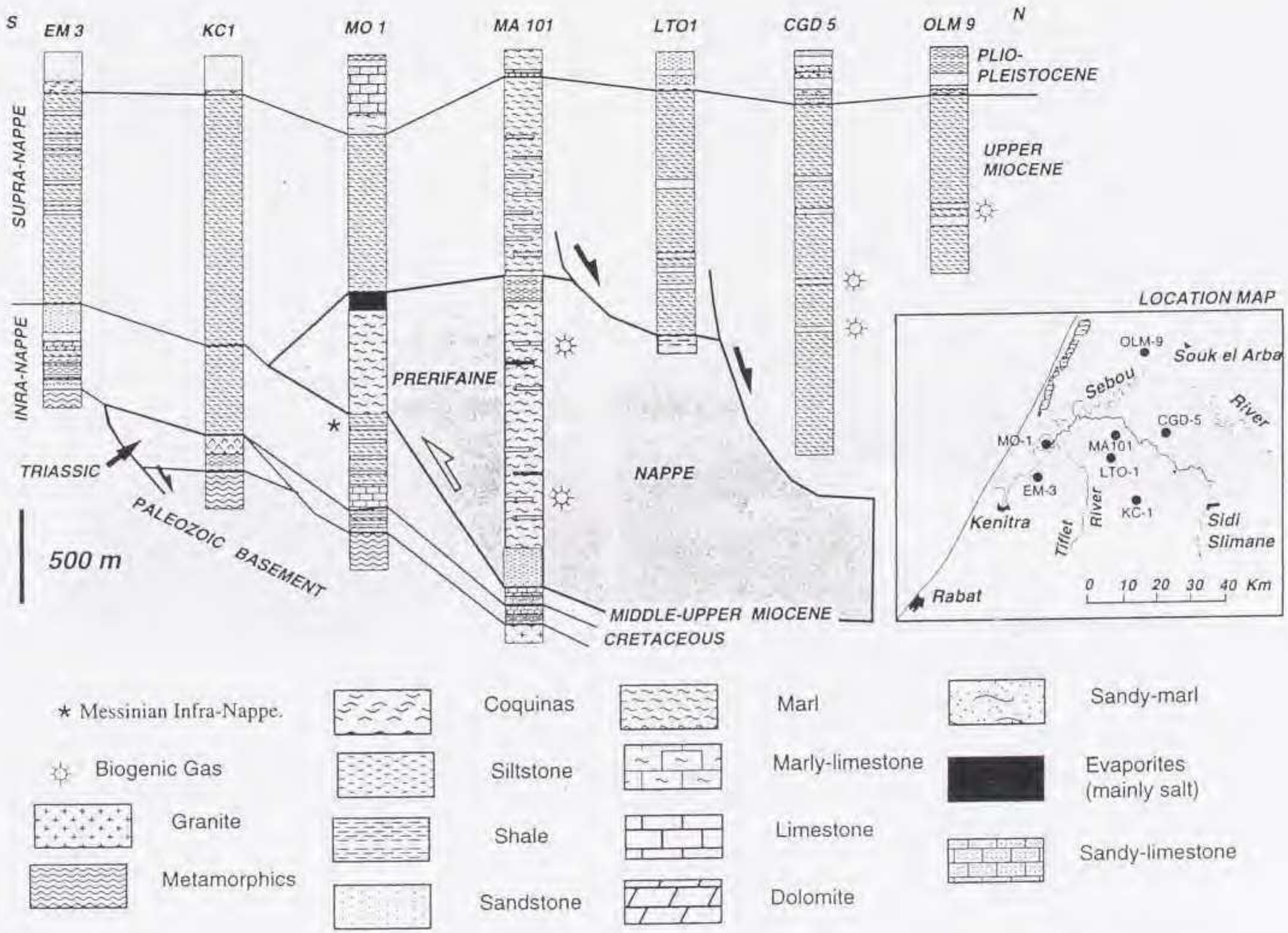

FIG. 5. Stratigraphic correlation of some selected wells of the Rharb Basin. Data from Wernli (1988), Feinberg (1986) and unpublished ONAREP reports.

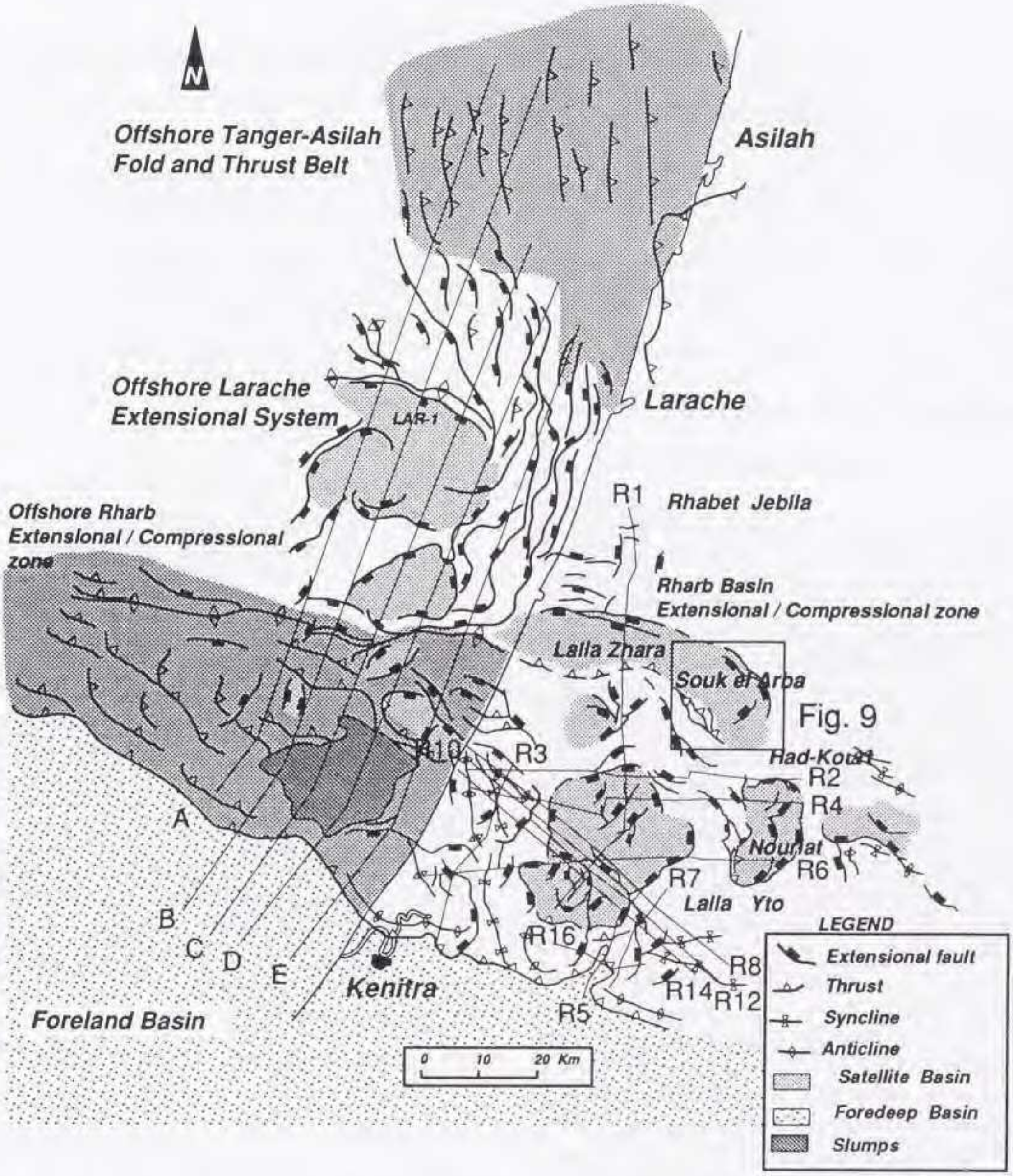

FIG. 6. Structural map of Northwestern Morocco with indication of the major structural domains consider in this study.

3.1.1 Offshore Tanger-Asilah / Fold and Thrust Belt

The northern part of the Moroccan Atlantic margin consists of westerly-vergent folds and thrusts. Fold axes and thrusts strike NNW-SSE, following the general trend of the Rif Cordillera (Fig. 6). They represent the continuation of the structures of the Tanger and Habt units exposed in the western Tanger peninsula (Suter, 1980b). The quality of the seismic data in this area is mediocre, and there are some regions with virtually no useful data.

3.1.2 Offshore Larache / Extensional Zone

The frontal thrusts of the Western Rif Cordillera extend further west into the region offshore Tanger-Asilah. Thrusts and related folds are cross-cut by NW-SE trending SW-dipping low-angle listric normal faults (Enclosure 1). The structure of this region is defined by troughs and ridges. Extensional basins are bounded by several anostomosing listric normal faults that sole out into a basal low-angle detachment which offsets the top of the accretionary wedge (Fig. 6). This network of anostomosing faults results in extensional horses that merge with each other and are superimposed on the accretionary wedge. Normal faults trend N-S, nearly parallel to the present day shoreline, and dip towards the west. E-W oriented sections (see Enclosure 1) show strongly rotated blocks on the hangingwall of the low-angle extensional detachment. In the eastern portion of these sections, growth-faulting results in large Supra-Nappe expansion controlled by westward-dipping normal faults that sole out into the basal detachment. Sediments above the extensional system show significant fault growth. In the central portion of the area, the top of the Nappe attains depths of 3.5 sec (TWT). The basal detachment of the extensional system steps down from 0.5 sec in the east to 3.5 sec in the west. The aparent transport direction of this extensional system is to the west. Nearly E-W oriented shale ridges are present in the central part of the extensional system; these were caused by shale withdrawal induced by extensional displacement.

3.1.3 Offshore Rharb / Frontal Imbricates-Extensional-Compressional Zone

This area is located west of the southern Rharb Basin, between the confluence of the Sebou River and the village of Moulay Bou Selham. High quality seismic data in this region show the details of the frontal part of the accretionary complex and the northernmost portion of the Rif foredeep. The Offshore Rharb area displays a combination of compressional and extensional elements (Fig. 6). In this complex area, NW-SE trending normal faults and occasional NE-SW-oriented normal faults cut NW-SE trending SW-vergent folds and thrusts. To the east of the area, normal faults share the same décollement level as thrust faults, defining toe-thrusts that accommodate the normal fault displacement (see Enclosure 1).

The frontal part of the wedge is characterized by closely spaced NW-SE trending, NE-dipping thrust faults that define a zone of frontal imbricates. Lateral and oblique ramps related to these frontal thrusts are common in the central and western portions of the area (Enclosure 1). The front of the accretionary complex has a NW-SE orientation (Fig. 6).

The structure of this area is well constrained by high quality seismic data. Dip lines are those trending perpendicular to the leading edge of the accretionary complex, that is NE-SW. Strike lines are those trending roughly parallel to the front of the wedge, that is NW-SE.

The most conspicuous features shown by the dip NE-SW sections are:

(a) The wedge-like geometry of the Prerifaine Nappe.
(b) Imbrications within the Infra-Nappe authochthonous succession.
(c) Frontal thrusts within the Nappe.
(d) Extensional faults crosscutting the Nappe.
(e) A northwestward-dipping basement beneath the Nappe.

(f) The northernmost portion of the foredeep.
(g) Frontal slumps

The strike sections show the following structural features:

(a) Steeply-dipping basement-involved faults offsetting the base of the Infra-Nappe units.
(b) Eastward thinning of the Prerifaine-Nappe.
(c) Lateral ramps of the frontal imbricates.
(d) Westward progradation of the Supra-Nappe succession.
(e) Frontal slumps and detached units.

3.1.4 Rharb Basin / Frontal Imbricates-Extensional-Compressional Zone

The topographic Rharb Basin overlaps the western front of the Rif Cordillera and its foreland (Fig. 2). It is bounded to the east and north by the frontal ranges of the Rif Cordillera and to the west by the Atlantic coast. The southern limit is the Paleozoic Moroccan Meseta. The surface expression of the Rharb Basin is a fluvial-alluvial coastal plain drained by the Sebou River. Subsurface data presented in this paper display the structure of the Neogene sedimentary succession of the Rharb Basin and the underlying Prerifaine Nappe.

South of the imbricated zone represented by the Asilah, Habt and Tanger units (Suter, 1980b) most of the structure of the accretionary wedge is controlled by extensional structures (see Fig. 6 and Enclosures 1 and 2). Extensional basins are located between the Rif fold and thrust belt and the leading edge of the accretionary wedge (Prerifaine Nappe). The structure of the Rharb Basin does not consist of well defined half-grabens but it is composed by a complex set of extensional and locally compressional basins (Fig. 6, Enclosure 2). These "satellite"[1] basins are bounded by several anostomosing listric normal faults which sole out into a basal low-angle detachment offseting the top of the accretionary wedge. Often extensional structures in the rear are coeval with conpressional toe-thrusts at the front of these "satellite" basins. The orientation of main faults is variable and random. Eventhough there is controversial data on the timing of development of these basins, most of them are Tortonian-Messinian in age. Growth is limited and most of the supra-nappe sediments are characterized by parallel bedding, which suggests fast extensional collapse. Basal re-deposited shallow-water sandstones and anoxic marls with occasional siltstone beds fill these extensional basins. Anoxia is the result of the extensional topography at the top of the Prerifaine Nappe, which involves highs and lows (Cirac and Peypouquet, 1983). In the cover sequence, rapid facies changes through time suggest also rapid extensional collapse of the Nappe (Flinch, 1993).

In the southern part of the Rharb Basin compressional structures associated with the front of the Prerifaine Nappe are observed (Enclosure 2). They consist of NE-SW trending anticlines and synclines related to SW-vergent imbricates of the Prerifaine Nappe. The southern area is occupied by E-W and N-S trending troughs associated with extensional faults superimposed on top of the Nappe. The structure of the central part of the Rharb Basin consists of E-W, N-S and NE-SW trending extensional troughs bounded by low-angle listric normal faults (Fig. 6). Depocenters in excess of 4500 meters occur southwest from Mechra bel Ksiri. (Dakki, 1992). Three of these basins are located in the contact between the foothills of the Rif and the Rharb Basin, namely: the Lalla-Zhara, Souk el Arba (Fig. 7) and Nouriat Satellite Basins. All these basins are characterized by rearward extension and frontal compression, which defines large scale toe-thrusts. The sedimentary fill of these basins, consists mostly of Tortonian-Messinian marls, with occassional interbedded sandstones and siltstones. Shallow biogenic gas, and locally oil has been recovered from the Aïn Hamra area (see Fig. 7 for location). The presence of Cretaceous source oil at a very shallow level, few hundred meters, suggests a connection between the

[1] The term **satellite basin** is preferred to piggy-back basin because of the presence of normal faults combined or not with thrust faults. The mechanics of these basins is therefore different than conventional thrust-related piggy-back basins in the sense of Ori and Friend (1984).

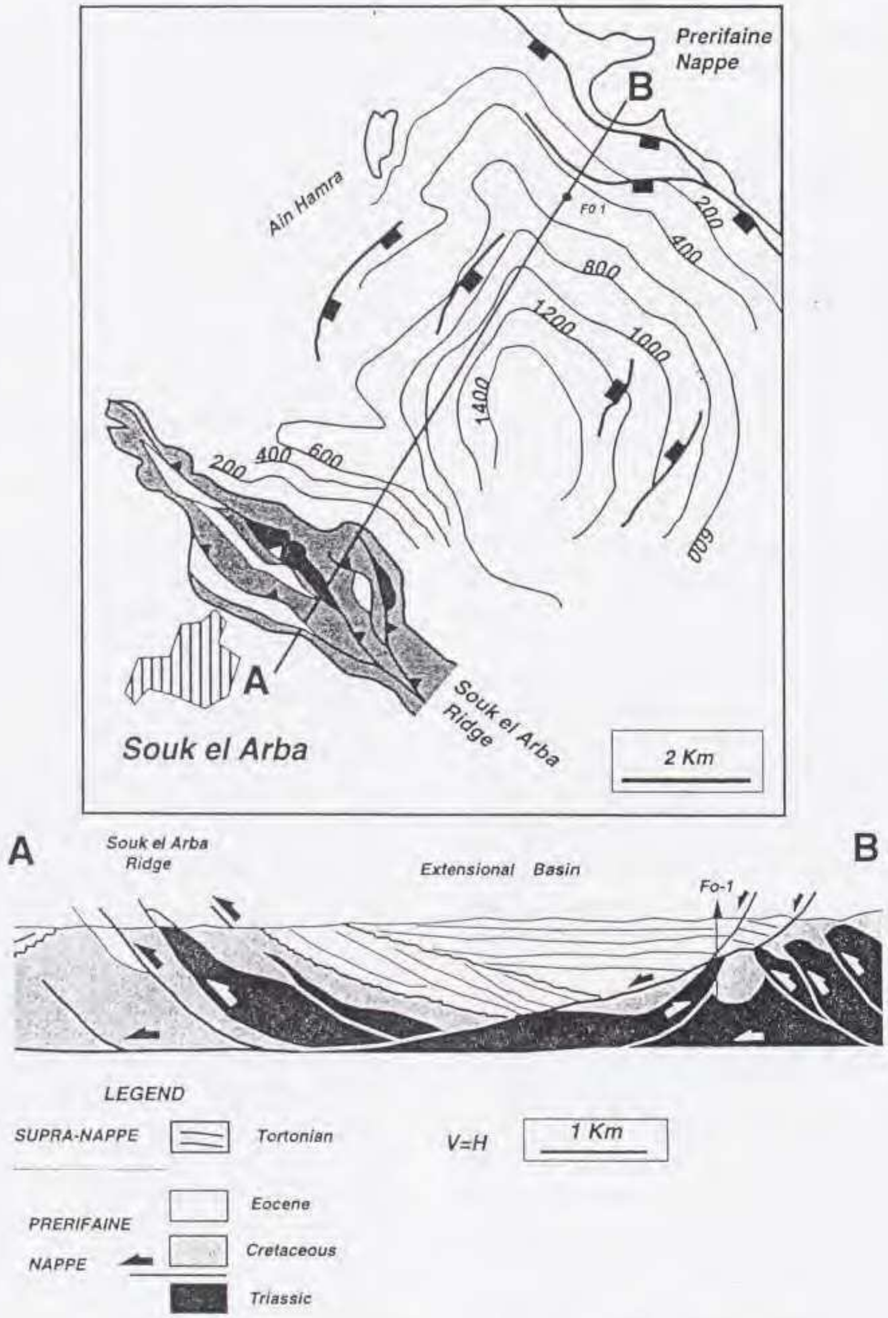

FIG. 7. Structural map and cross-section along the Souk el Arba Satellite Basin.

extensional decollement and the underlying thrust faults within the Nappe.

The structure of the Rharb Basin is illustrated by a series of composite regional seismic lines. Enclosure 2 shows four regional dip sections and eight strike lines. The dip lines are roughly oriented NE-SW, trending nearly perpendicular to the leading edge of the Prerifaine Nappe. The strike lines are oriented perpendicular to the transport direction of the Nappe and parallel to its leading edge. Enclosure 2 displays five northeastward trending sections in the Lalla Yto area. Three E-W oriented sections, extending from the Nouriat region in the east to the Sebou region in the west; four NE-SW trending sections; two in Lalla Yto in the East, one through the central Rharb extending from Rhabet Jebila in the north to Lalla Yto in the south and one along the Sebou coastal area. On the basis of seismic character and structural significance, the same seismic units are recognized as in the offshore sections (Enclosure 1), that is: Basement, Infra-Nappe, Nappe and Supra-Nappe.

The most characteristic features evidenced on the dip lines (odd numbered sections of Enclosure 2) are:

(a) The wedge-like character of the Prerifaine Nappe.
(b) The northward dip of the basement and the infra-nappe succession underneath the Prerifaine Nappe.
(c) Southward vergent imbricates involving infra-nappe sediments.
(d) Extensional faults offsetting the top of the nappe.
(e) Clinoformal patterns in the Supra-Nappe units indicating southwestward progradation.

The most conspicuous features evidenced in the strike lines (even numbered sections of Enclosure 2) are:

(a) The thickness change of the Infra-Nappe unit.
(b) Nearly vertical faults offsetting the Infra-Nappe succession.
(c) Lateral ramps of the extensional system (the oblique orientation of the section reveals lateral ramps).

3.1.5 Onshore-Offshore Rabat / Foredeep

South of the leading edge of the Prerifaine Nappe, the structures consist of NE-dipping Infra-Nappe units that plunges beneath the accretionary wedge. Basement-involving nearly-vertical normal faults disrupt the otherwise continuous Infra-Nappe succession (see Enclosures 1 and 2). Some of these faults account for a thickness change of the infra-nappe succession but do not affect the overlying sediments (Enclosure 2); these faults are related to the Central Atlantic rift system (Flinch, 1993). Other faults do not account for any thickness change of the infra-nappe units but offset the foreland succession, these faults are related to flexural extension induced by tectonic loading of the foreland by the Prerifaine Nappe (Enclosure 1) (Flinch, 1993) as seen also in other foreland basins (Bradley and Kidd, 1991). An angular unconformity which is onlapped by the foreland sequence corresponds to the "basal foredeep unconformity" in the sense of Bally (1989). Locally, sediments derived from the craton, prograding into the foredeep can be recognized in the southern part of the area (see Enclosure 1). This region is located in the offshore prolongation of the Rif foredeep, located east from Rabat (see Figs. 2 and 6 for location).

4 DISCUSSION

The overall composition and type of deformation of the external Betic and Rif domain suggests the involvement of an accretionary prism consisting of deep-water sediments, that was emplaced on the attenuated Iberian and African passive margins in response to westward motion of the Alborán domain during Middle Miocene to Pliocene time.

The timing of deformation and the age of the sediments involved suggest an accretionary progression towards the external portion of the arc. Deformation within the accretionary complex was previously explained by several phases of deformation and by gravitational tectonics (Feinberg, 1976; Vidal, 1977; Feinberg, 1986). In contrast, a continuous accretion model, similar to current models of more conventional accretionary complexes (e.g. Dickinson and Seely, 1979; von Huene 1986), appears to apply here. On the basis of field data and seismic data, a block diagram of the accretionary complex was constructed (Fig. 8). Note that the accretionary wedge is presumably underlain by a normal to transitional continental crust which dips towards the Mediterranean (A-type subduction); this contrast with the more conventional accretionary wedges that are related to subducting oceanic lithosphere (B-type subduction).

The style of extension present in the external part of the Gibraltar Arc is similar to the Gulf of Mexico (Worrall and Snelson, 1989). It consists of listric normal faults rooted into a low-angle extensional detachment composed of overpressured shales and marls. In the offshore Larache area, the transport direction of the extensional system coincides with the geometry of the continental slope, and is nearly parallel to the present day shelfbreak.

There is no clear relationship between the frontal compressional zone (Offshore Rabat) and the rear extensional system described above. The lack of seismic resolution and penetration in the lower part of the seismic sections does not allow to see if down-dip thrusts and folds share the same decollement as the up-dip low-angle normal faults. Therephore, it is difficult to demonstrate if extensional displacement is compensated by frontal compression at a regional scale. The most frontal parts of the Gibraltar Arc accretionary wedge may represent compressional belts that are the result of rear extension, as suggested by Platt (1986) for other accretionary wedges. This type of deformation would represent the response of the system to the unstable oversteepened slope (critical taper theory) generated by the stacking of thrust slices within the wedge (Davis et al., 1983).

The three-dimensional diagram presented here has some important implications for the geology of the Betic and Rif Cordilleras. The Rif Cordillera consists of numerous structural units, which classically are referred to as "Nappes" (Suter, 1980b), however many of these units do not have the attributes of thrust sheets. Omission of strata or no duplication of the stratigraphic section are common to these units. A structural map of the Western Rif was put together integrating offshore and onshore subsurface data and field data based mostly on published geologic maps (Flinch, 1993) (Fig. 9). The relationship between the Prerifaine Nappe and the underlying units of the **External domain** can be observed particularlly well in the Had-Kourt/Teroual area (Fig. 10). Seismic data through the area permits to see the relationship between several stacked thrust-sheets (Fig. 11). The data presented here suggest that several geologic units referred to as "unites flottantes" or "Nappes rifaines superieures" (upper thrust sheets) (Wildi, 1983), are in fact satellite basins which overlie the accretionary wedge (Figs. 9, 10 and 11). These basins were deformed at the same time as the transport of the accretionary wedge towards the foreland, in response to the collision of the Alborán allochthonous terrane with the Iberian and African foreland. In the past, some of these Satellite basins were interpreted as out-of-sequence thrusting (Morley, 1992). Instead a model where the structure is the result of the piggy-back emplacement of sequences, that is, the upper units were emplaced first, the later emplacement of the lower units deformed the upper units from underneath. The first unit to be emplaced was the accretionary wedge and the underlying more landward passive margin units were emplaced afterwards (Fig. 11). This lead to widespread structural envelopment of the accretionary wedge (Flinch, 1993).The new concept presented here, significantly simplifies the structural framework of the Rif Cordillera. I postulate that these units may have a similar origin as the Neogene satellite basins of the offshore and onshore Rharb area.

The Ouezzane Unit (Hottinger and Suter in Durand-Delga, 1960-1962) of the external Western Rif is the most obvious example of such a complex of satellite basins. This unit was interpreted as a thrust sheet or "nappe" located on top of the Prerifaine nappes (Suter, 1965; 1980b). In the so-called flysch domain, the Numidian Unit represents the highest structural unit which is located above the underlying imbricates; also this unit may represent

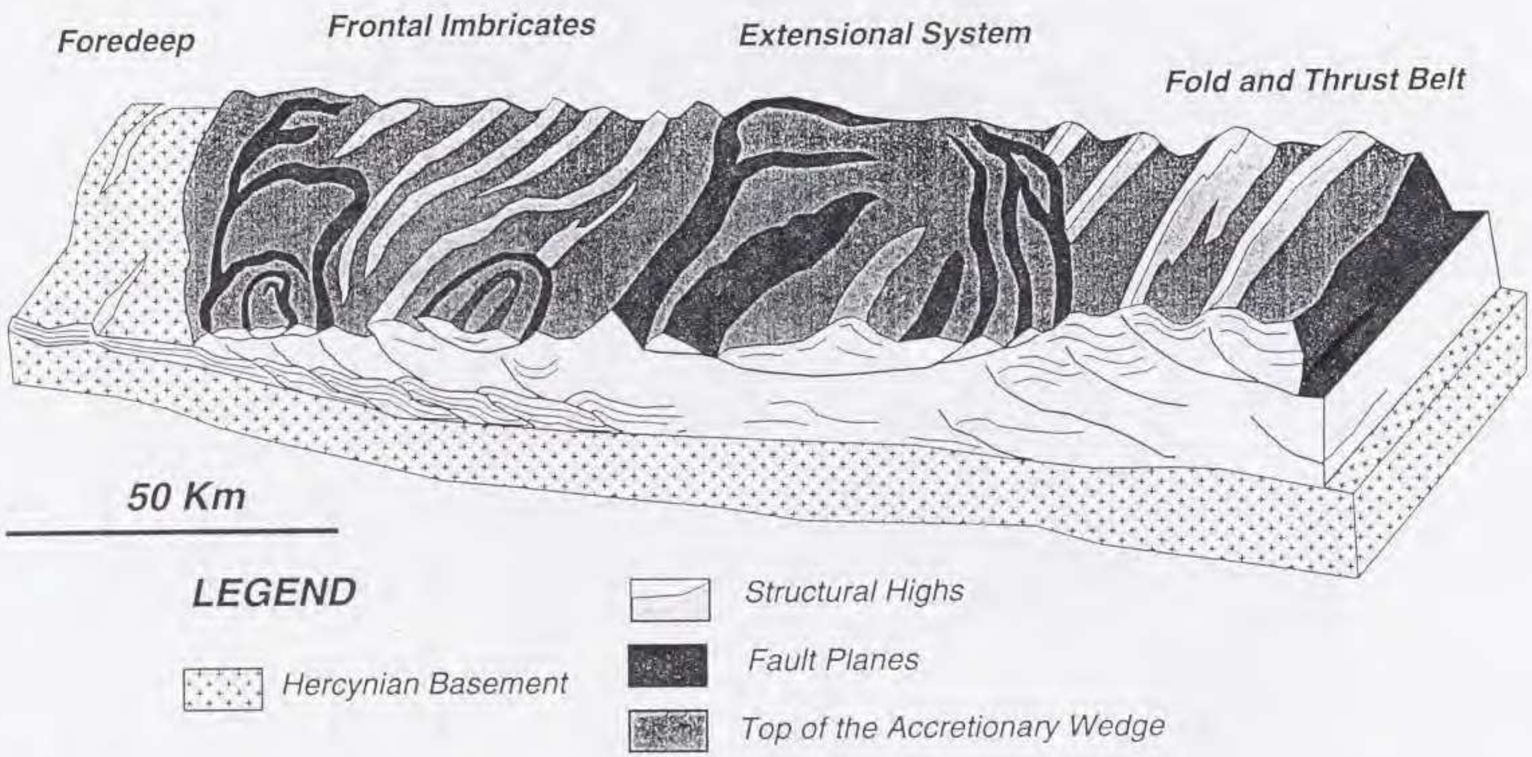

FIG. 8. Three-dimensional block-diagram of the accretionary wedge in the External Western Rif.

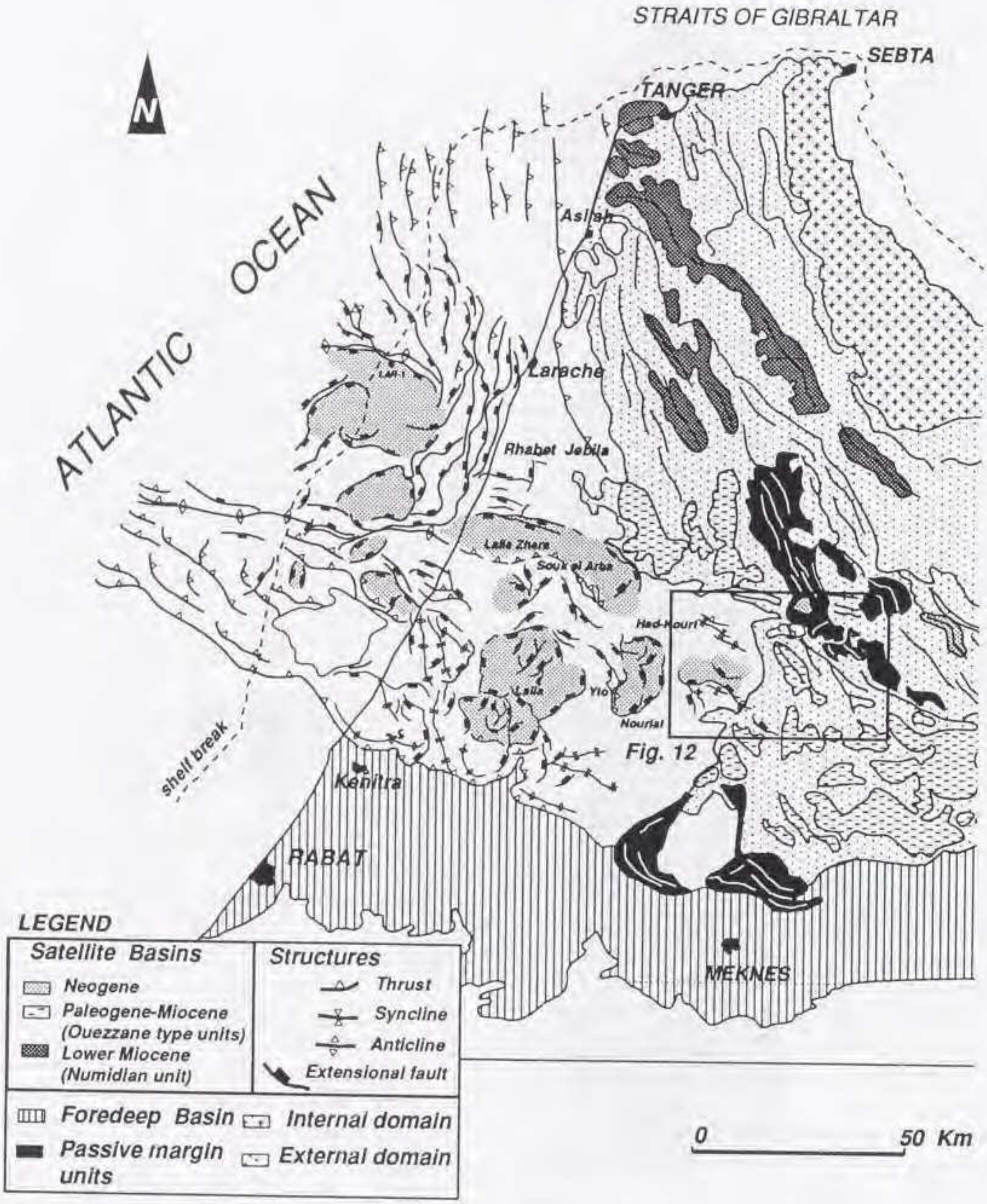

FIG. 9. Structural map of the Western Rif integrating onshore and offshore data, after Flinch (1993).

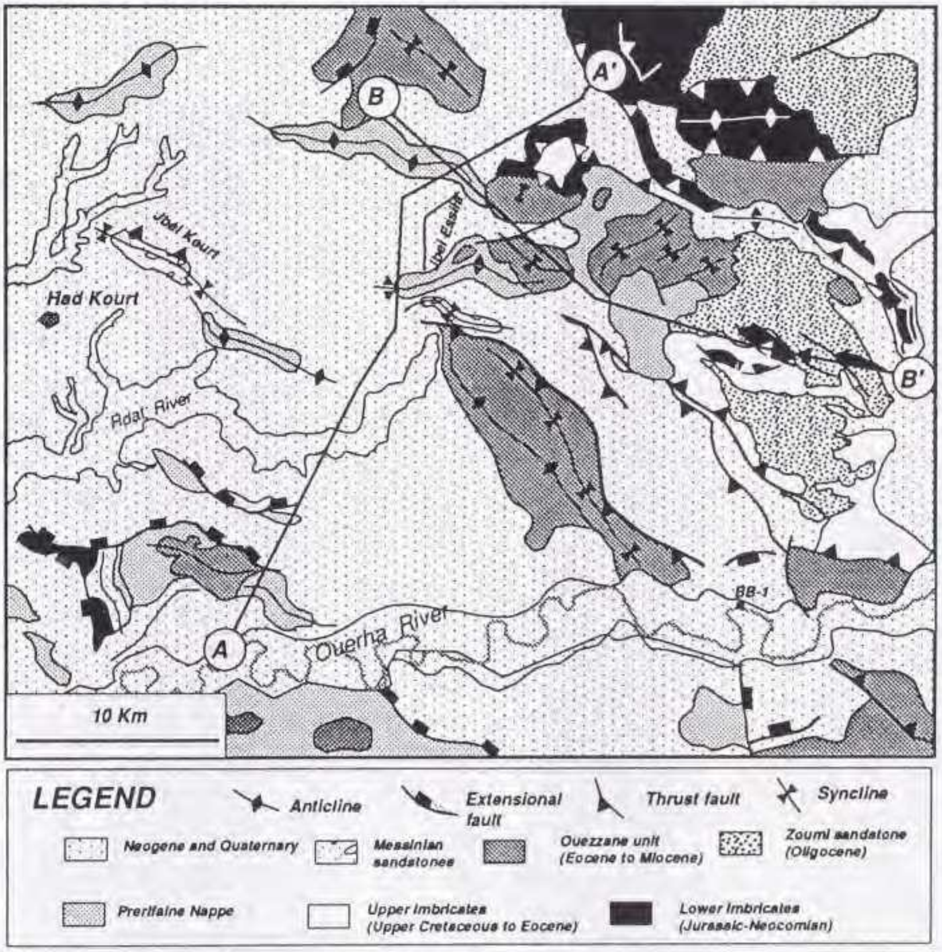

FIG. 10. Structural map of the Had Kourt-Teroual area. Modified from the Service Géologique du Maroc 1:50,000 scale maps of Had Kourt (1984) and Teroual (1990).

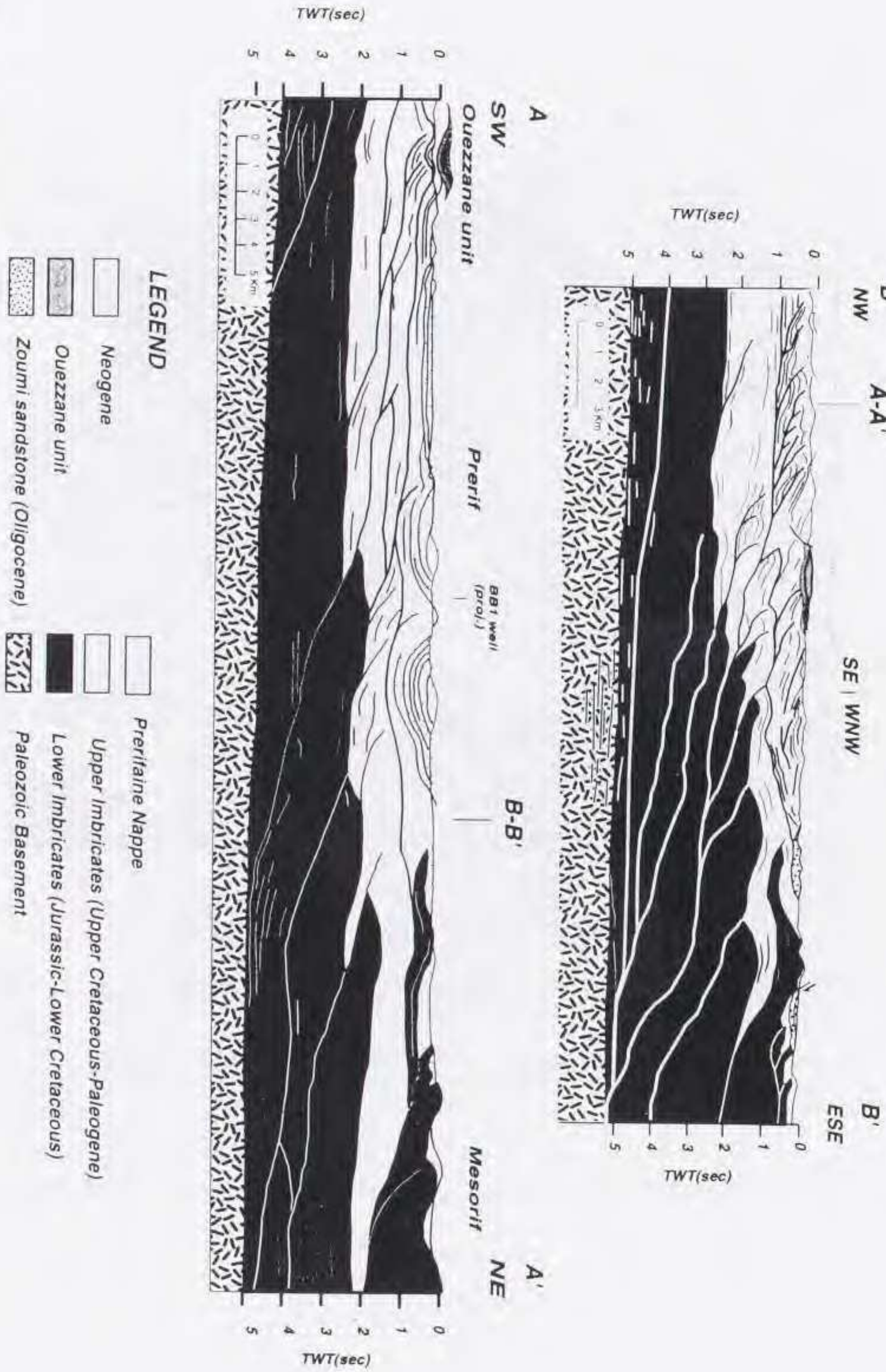

FIG. 11. Line drawings from seismic sections along the Had Kourt - Teroual area.

a set of satellite basins. The Numidian sandstone was deposited on top of imbricates involving previously deposited turbiditic deposits of the Tanger and Ketama Units. I suggest that the Numidian Sandstone represents the turbiditic Satellite basin fill which overlies the Oligocene-Early Miocene accretionary wedge of the Gibraltar Arc. These Satellite Basins appear to be detached from the underlying units by thrust or normal faults, thus simulating an independent thrust sheet. However, unlike real stacked thrust sheets, younger sediments overlie the deeper tectono-stratigraphic unit.

5 CONCLUSIONS

The frontal tectono-sedimentary complexes of the Betic and Rif Cordilleras, the Guadalquivir Allochthon and the Prerifaine Nappe, constitute an accretionary wedge which was superposed on the attenuated passive margin of Iberia and NW Africa during the Miocene phases of the Alpine orogeny.

The structure of the accretionary wedge consists of frontal imbricates, ridges, toe-thrusts and low-angle extensional detachments. The Supra-Nappe sediments involve compressional-extensional and extensional satellite basins trending parallel and perpendicular to the Arc. Satellite basins are not directly related to the opening of the Alborán Sea; instead they are due to oversteepening of the accretionary wedge and gravitational gliding down the continental slope.

Very rapid extensional collapse affected the accretionary wedge during Tortonian and Messinian time. The paleogeographic evolution, involving the superposition of deep-water facies onto shallow-water sediments and the lack of significant growth support this argument.

The style of extension is characterized by low-angle listric normal faults, similar to the Gulf of Mexico. Extensional displacement is compensated by frontal compression. Toe-thrusts are common structures in the frontal part of the Gibraltar Arc. An undisturbed upper part of the prograding Supra-Nappe succession suggests that the accretionary wedge was stabilized during Pleistocene time.

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REFERENCES

Andrieux, J., D. Frizon de Lamotte and J. Braud (1989), "A structural scheme for the Western Mediterranean area in Jurassic and Early Cretaceous times". *Geodinamica Acta*, **3**, 1, pp. 5-15.

Bally, A.W. (1989), Phanerozoic basins of North America. In *The Geology of North America-An overview* (Edited by Bally, A.W. and A.R. Palmer). Geological Society of America, Boulder, Colorado, pp. 397-446.

Blankenship, C.L. (1992), "Structure and palaeogeography of the External Betic Cordillera, southern Spain". *Marine and Petroleum Geology*, **9**, pp. 256-264.

Bradley, D.C. and W.S.F. Kidd (1991), "Flexural extension of the upper continental crust in collisional foredeeps". *Geol. Soc. America Bull.*, **103**, pp. 1416-1438.

Bruderer, W. and R.G. Lévy (1954), "Considerations sur la "Nappe Prerifaine" d'apress les travaux de la société Chérifienne des Pétroles". *Comptes Rendus 19 Session International Congress 1952. Alger.*, **21**, pp. 277-294.

Cirac, P. and P. Peypouquet (1983), "Paléoenvironnements néogènes dans les bassins océaniques ibéro-marocains. Relations paléohydrologiques Méditerranée-Atlantique". *Oceanol. Acta.*, **6**, 2, pp. 147-156.

Daguin, F. (1927), *Contribution a l'étude géologique de la région prérifaine (Maroc occidental)*. Notes et Mem. Serv. Mines et Carte Géol. Maroc., 413 p.

Dakki, M. (1992), *Gaz biogenique dans le bassin du Rharb. Petroleum exploration in Morocco. First conference on Petroleum Exploration. February 1992. Rabat. 27.*

De Jong, K. (1991), *Tectono-metamorphic studies and radiometric dating in the Betic Cordilleras (SE Spain)*. Ph.D. thesis, Vrije Universteit, Amsterdam, 204 p.

Davis, D.M., J. Suppe and F.A. Dahlen (1983), "Mechanics of fold-and-thrust belts and accretionary wedges". *Journal of Geophysical Research*, **88**, pp. 1153-1172.

Dercourt, J., L.P. Zonenshaïn, L.E. Ricou, V.G. Kazmin, X. Le Pichon, A.L. Knipper, C. Grandjacquet, I.M. Sborshchikov, J. Boulin, O. Sorokhitin, J. Geyssant, C. Lepvrier, B. Biju-Duval, J.C. Sibuet, L.A. Savostin, M. Westphal and J.P. Laner (1986), "Geological evolution of the Tethys belt from Atlantic to Pamir since Liassic". *Tectonophysics*, **123**, 1-4, pp. 241-315.

Dewey, J.F., M.L. Helman, E. Turco, D.H.W. Hutton and S.D. Knott (1989), Kinematics of the western Mediterranean. In *Alpine Tectonics* (Edited by Coward, M.P. and R.G. Park). *Geological Society Special Publication*, **45**, pp. 265-283.

Dickinson, W.R. and D.R. Seely (1979), "Structure and stratigraphy of forearc regions". *AAPG Bull.*, **63**, 1, pp. 2-31.

Durand-Delga, M., L. Hottinger, J. Marçais, M. Mattauer, Y. Milliard and G. Suter (1960-62), Données actuelles sur la structure du Rif. In *Livre-mémoire P. Fallot. Mém. h. sér. Soc. Geol. France*, **1**, pp. 399-422.

Favre, Ph., G. Stampfli and W. Wildi (1991), "Jurassic sedimentary record and tectonic evolution of the northwestern corner of Africa". *Palaeogeography, Palaeoclimatology, Palaeoecology*, **87**, pp. 53-73.

Favre, Ph. and G. Stampfli (1992), "From rifting to passive margin: the examples of the Red Sea, Central Atlantic and Alpine Tethys". *Tectonophysics*, **215**, pp. 69-97.

Feinberg, H. (1976), "Mise en place, au Pliocène, d'une nappe de glissement a l'extrémité sud-occidentale de la chaene du Rif (Maroc)". *C. R. somm. Soc. Geol. France*, **6**, pp. 273-275.

Feinberg, H. (1986), *Les series tertiaries des zones externes du Rif (Maroc)*. Notes et Memoires du Service Géologique, **315**. Service Geol. du Maroc, 192 p.

Flinch, J.F. and A.W. Bally (1991), "Extensional collapse in an Accretionary Complex: Gibraltar Arc (Western Mediterranean)". *Geological Society of America Abstracts with Programs*, p. 55, A 130.

Flinch, J.F. (1993), *Tectonic evolution of the Gibraltar Arc*. Unpublished Ph.D. Thesis, Rice University, Houston, Texas, 381 p.

Fontboté, J. (1983), Zonas Internas y unidades adyacentes de la Cordillera Bética. In *Libro Jubilar J. M. Rios, Geologia de España* (Edited by Comba, J.A.), Instituto Geológico y Minero de España, Madrid, Spain, pp. 251-343.

Galindo-Zaldívar, J., F. Gonzalez-Lodeiro and A. Jabaloy (1989), "Progressive extensional shear structures in a detachment contact in the Western Sierra Nevada (Betic Cordilleras, Spain)". *Geodinamica Acta*, **3**, 1, pp. 73-85.

García-Dueñas, V. and J. Martínez-Martínez (1988), "Sobre el adelgazamiento mioceno del Dominio Cortical de Alborán, el Despegue Extensional de Filabres (Béticas orientales)". *Geogaceta*, **5**, pp. 53-55.

García-Dueñas, V., J.C. Balanyá and J.M. Martínez-Martínez (1992), "Miocene extensional detachments in the outcropping basement of the northern Alborán basin (Betics) and their tectonic implications". *Geo-Marine Letters*, **12**, pp. 88-95.

García-Hernández, M., A.C. Lopez-Garrido, P. Rivas, C. Sanz de Galdeano and J.A. Vera (1980), "Mesozoic palaeogeographic evolution of the External Zones of the Betic Cordillera". *Geol. Mijnb.*, **59**, pp. 155-168.

Gigout, M. (1951), "Etudes géologiques sur la Méséta marocaine occidentale (arrière-pays de Casablanca, Mazagan et Safi)". *Trav. Ins. sci. chérif. Notes et Memoires Serv. Geol. Maroc.*, **86**, 507 p.

Instituto Geológico y Minero de España (1987), *Contribución de la exploración petrolífera al conocimiento de la geologia de España*. Instituto Geológico y Minero de España, Madrid, Spain. 465 p.

Lajat, D., B. Biju-Duval, R. Gonnard, J. Letouzey and E. Winnock (1975), "Prolongement dans l' Atlantique de la partie externe de l' Arc betico-rifain". *Bull. Soc. Geol. France*, **7**, 17,4, pp. 481-485.

Malod, J.A. and J. Didon (1975), "Etude géologique par sismique réflexion et carottages de roches du plateau continental de la baie de Cadix (Espagne)". *C. R. Acad. Sci. Paris*, **280 D**, pp. 149-152.

Malod, J.A. and D. Mougenot (1979), "L'histoire géologique néogène du golfe de Cadix". *Bull. Soc. Geol. France*, **21**, 5, pp. 603-611.

Martín-Algarra, A. (1987), *Evolución geológica Alpina del contacto entre las zonas internas y las zonas externas de la cordillera Bética*. Ph.D. Thesis, Univ. de Granada, Spain, 1171 p.

Michard, A. (1976), *Elements de geologie Marocaine*. Notes et Memoires du Service Géologique du Maroc, **252**, 408 p.

Morley, C.K. (1992), "Tectonic and sedimentary evidence for synchronous and out-of-sequence thrusting, Larache-Acilah area, Western Moroccan Rif". *Journal of the Geological Society*, **149**, pp. 39-49.

Ori, G.G and P.F. Friend, (1984), "Sedimentary basins, formed and carried piggy-back on active thrust sheets". *Geology*, **12**, pp. 475-478

Perconig, E. (1960-62), "Sur la constitution gèologique de l'Andalousie Occidentale, en particulier du bassin du Guadalquivir (Espagne méridionale)". *Liv. Mem. prof. Fallot. Mèm. hors ser. S. G. F.*, **1**, pp. 229-256.

Platt, J.P. (1986), "Dynamics of orogenic wedges and the uplift of high-pressure metamorphic rocks". *Geol. Soc. Am. Bull.*, **97**, pp. 1037-1053.

Suter, G. (1965), "La région du Moyen Ouerha (Rif, Maroc): Etude préliminaire sur la stratigraphie et la tectonique". *Notes Serv. Geol. Maroc*, **24**, 183, pp. 7-17.

Suter, G. (1980a), *Carte Géologique de la Chaîne Rifaine. 1:50,000*. Serv. Geol. Du Maroc. Notes et Memoires 245a.

Suter, G. (1980b), *Carte Structurale de la Chaîne Rifaine. 1:50,000*. Serv. Geol. Du Maroc. Notes et Memoires 245b.

Termier, H. (1936), *Etudes géologiques sur le Maroc Central et le Moyen-Atlas Septentrional. 3 vol.* Notes et Memoires Serv. Mines et Carte Geol. Maroc, **33**, 1566 p.

Tilloy, R. (1955a), *Feuille de Fès-Ouest, Note explicative. Carte Geol. du Maroc au 1/100,000. Notes et Mémoires 109 bis*. Service Géologique du Maroc, Rabat, 62 p.

Tilloy, R. (1955b), *Feuilles de Rabat et de Sidi Yahya du Rharb. Note explicative. Carte Geol. du Maroc au 1/100,000. Notes et Mémoires 106 bis and 107 bis*. Service Géologique du Maroc, Rabat, 62 p.

Tilloy, R. (1955c), *Feuille de Souk el Arba du Rharb. Note explicative. Carte Geol. du Maroc au 1/100,000. Notes et Mémoires 104 bis*. Service Géologique du Maroc, Rabat, 62 p.

Tilloy, R. (1955d), *Feuille d'Ouezzane, Note explicative. Carte Geol. du Maroc au 1/100,000. Notes et Mémoires 105 bis*. Service Géologique du Maroc, Rabat, 62 p.

Vera, J.A. (1981), Correlación entre las Cordilleras Béticas y otras cordilleras alpinas durante el Mesozoico. In *Programa Internacional de Correlación geológica P.I.C.G. Real. Acad. Cienc. Exact. Fis. Nat.*, **2**, pp. 129-160.

Vera, J.A. (1983), "Las Zonas Externas de las Cordilleras Béticas". In *Libro Jubilar J. M. Rios, Geologia de España* (Edited by Comba, J.A.). Instituto Geológico y Minero de España, pp. 218-251.

Vidal, J.C. (1977), "Structure actuelle et évolution depuis le Miocène de la chaene rifaine (partie sud de l'arc de Gibraltar)". *Bull. Soc. Geol. France*, **19**, 4, pp. 789-796.

Von Huene, R. (1986), *Seismic Images of Modern Convergent margin. Tectonic Structure*. AAPG Studies in Geology 26, Tulsa (Oklahoma), 60 p.

Wernli, R. (1988), *Micropaléontologie du Néogène postnappes du Maroc septentrional et description systématique des foraminifères planctoniques*. Notes et Memoires du Service Géologique du Maroc, **331**, 270 p.

Wildi, W. (1983), "La chaîne tello-rifaine (Algérie, Maroc, Tunisie): structure, stratigraphie et évolution du Trias au Miocène". *Revue de Géologie Dynamique et de Géographie Physique*, **24**, 3, pp. 201-297.

Worrall, D.M., and S. Snelson (1989), Evolution of the northern Gulf of Mexico, with emphasis on Cenozoic growth faulting and the role of salt. In *The Geology of North America, an overview, vol. A* (Edited by Bally, A.W. and A.R. Palmer). The Geol. Soc of America, Tulsa, Oklahoma, pp. 97-138.

Ziegler, P.A. (1987), Late Cretaceous and Cenozoic intraplate compressional deformations in the Alpine foreland a geodynamic model. In *Compressional Intra-Plate Deformations in the Alpine Foreland* (Edited by Ziegler, P.A.). *Tectonophysics*, 137, pp. 389-420.

APPENDIX

In the following I will describe the structure of the seismic line drawings presented in Enclosure 2.

Regional Section R1

This N-S and NE-SW regional section extends from Rhabet Jebila to Lalla Yto. In the northern portion of the transect a series of southward-dipping growth faults offset the top of the Prerifaine Nappe. The region of Rhabet Jebila-Lalla Zhara consist of a northern extensional satellite basin and a southern ridge. The basal decollement is located at 2 seconds recording time. Thrusts connected with this basal detachment are present within the Nappe. The maximum thickness (2.5 sec) (1800 meters) of the Supra-Nappe Neogene is attained in the central part of the section. The southern part of the section (Lalla Yto region) is represented by lateral ramps merging into the basal decollement of the Prerifaine Nappe. Antithetic and synthetic normal faults also offset the Mio-Pliocene boundary. Normal faulting is younger in this region than in the northern Rharb, where the Mio-Pliocene boundary is not offset.

Regional Section R3

This northeastward trending section follows the Sebou River coastal plain and shows the wedge-shaped Prerifaine Nappe. In the southeastern portion of the section, gently northeastward-dipping Infra-Nappe reflectors unconformably overlie the Hercynian basement. The Supra-Nappe prograding units onlap directly the basal foredeep unconformity. Well EM-3, located in the foredeep region just in front of the Nappe, penetrated the whole sedimentary succession, encountering Cretaceous and Tortonian-Messinian Infra-Nappe and Plio-Pleistocene Supra-Nappe. North of the leading edge of the wedge, the Infra-Nappe unit is characterized by a basal zone of imbricated layered reflectors. The structure of the Prerifaine Nappe itself is characterized by northeastward-dipping thrust faults. Extensional faults are superimposed on the Nappe. Supra-Nappe units show a southward prograding clinoformal pattern. Well MO-1 penetrated the Nappe and Infra Nappe units, reaching the Paleozoic basement.

Regional Section R5

This NE-SW oriented section located in Lalla Yto illustrates essentially the same features as on section R3. Again, the geometry of the wedge, the basal imbricates of the Infra-Nappe unit, and the normal faults that cut the Supra-Nappe succession are the most interesting features shown on this profile. On the SE margin of the section, south of the leading edge of the Prerifaine Nappe i.e. in the foredeep, the Supra-Nappe units onlap directly on the northeastward-dipping Infra-Nappe reflectors, thus definnig the basal foredeep unconformity. Well KC-1, located in front of the Nappe, reaches the basement after penetrating Infra-Nappe Triassic, Cretaceous and Middle Miocene.

Regional Section R7

This northeastward trending section is located in the region of Lalla Yto, west of section R5. The section shows the same features as section R7. In the frontal part of the Nappe, extensional and compressional structures are detached at the same décollement level, thus defining toe-thrusts.

Regional Section R2

This section is oriented E-W, extending from the region of Nouriat to the Atlantic Coast. The line shows the subsurface expression of the contact between the Rharb Basin and the frontal ranges of the Rif. The eastern end of the section shows westward-dipping listric normal faults, responsible for the westward-thickening of the Supra-Nappe succession. Most normal faults merge into a low-angle extensional detachment. Rotated blocks develop in the hangingwall of the extensional system. Extension in the Nouriat area occurs mostly during Messinian time. Proceeding westward, the structure of the central Rharb Basin consists of a series of westward-dipping listric normal faults. Lateral ramps, suggesting a transport direction oblique to the plane of the section, are common in the central portion of the section. In the western part of the section (Sebou region), the base of the Prerifaine Nappe is at 3 sec recording time. Infra-Nappe layered reflectors are well imaged. Occasional thrusts are present within the Nappe. The Prerifaine Nappe is not significantly affected by extensional faults in this western area.

Regional Section R4

This E-W trending regional section is parallel to R2 and extends from Nouriat to the Atlantic. Most conspicuous on this section is the westward deepening of the top-of-the-Nappe extensional detachment. Ramps and flats define the geometry of the basal extensional detachment. The extensional décollement deepens down to 2.5 sec in the central part of the section. Supra-Nappe sediments fill the downthrown depressions of the extensional system. Only on the easternmost portion of the section is the Mio-Pliocene boundary offset by normal faults. In the Sebou region the basal decollement of the Prerifaine Nappe is imaged on the profile at 3 sec (TWT). Layered Infra-Nappe reflectors underlie the basal decollement.

Regional Section R6 (see Fig. 4)

This section shows lisia and Africa, defining the geodynamics of the region (Dercourt et al.; 1986; Andrieux et al., 1989; Dewey et al.,1989; Ziegler, 1987; Favre and Stampfli, 1992).

Regional Sections R8, R10, R12, R14

These sections located in the Lalla Yto area are closely spaced (2 to 3 km). They are oriented NW-SE, providing more examples of strike sections across the Rharb Basin. Wells MA-101 and MO-1 were tied into the seismic. The basal décollement steps down from 1.8-2 to 3-3.2 sec recording time. Thickness changes of the Infra-Nappe succession coincide with the location of nearly vertical faults that offset the basement. The top of the basement and the overlying Infra-Nappe succession dip to the northwest. The Prerifaine Nappe is thrusted onto Cretaceous and Middle Miocene Infra-Nappe sediments that overlie the Hercynian basement of the Moroccan Meseta. Lateral ramps of listric normal faults offset the top of the Nappe and the overlying Supra-Nappe succession.

Regional Section R16

This section across the central Lalla Yto area is roughly oriented WNW-ESE. The section is located near the leading edge of the Prerifaine Nappe. A complete Infra-Nappe succession penetrated by the KC-1 well consists of a Triassic half-graben and is unconformably overlain (Post-Rift unconformity) by parallel-bedded horizontal Cretaceous and Miocene sediments. Plio-Pleistocene units show a downlap pattern that suggests west-northwestward progradation.

Enclosures

Enclosure 1 Line-drawings of regional seismic sections, offshore Northwestern Morocco. Sections A, B, C, D, E: offshore Asilah-Rabat. Sections F, G, H, I: offshore Larache.

Enclosure 2 Line-drawings of regional seismic sections: Rharb Basin, onshore Northwestern Morocco.